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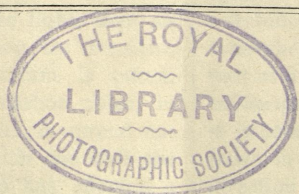

CANTOR LECTURES

ON

PHOTOGRAPHY AND THE SPECTROSCOPE.

BY

CAPT. ABNEY, F.R.S.

DELIVERED BEFORE THE SOCIETY OF ARTS, APRIL 20TH AND 27TH, 1885.

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PHOTOGRAPHY AND THE SPECTROSCOPE,

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LECTURE I.—DELIVERED APRIL 20, 1885.

Every lecturer, when he begins, must have a text of some description, and I propose to make my text for the lectures a plate exposed to the spectrum. You see before you a spectroscope comprising a collimator, two prisms, and a camera, with a lens of 13-inch focal length, and in this slide is a sensitive collodion plate.

The spectrum of the hot carbons of the electric light is upon the focussing screen which you see before you, and I will simply expose this plate, and refer to it from time to time as my lecture continues.

The plate is given six seconds' exposure to the light of that spectrum, and now in the subdued light coming from this lantern, whose sides are covered with translucent orange paper, I see the picture is coming out under the action of the ferrous oxalate developer. After fixing, we see that we have the photographed spectrum on the plate.

This is the text on which I have to hang my lectures. We have three things to consider. First of all, we have got the light, then we have the apparatus, and then the sensitive material on which the spectrum is taken. The white light from the carbon poles, in passing through the apparatus, is spread out into a coloured band, which we call the spectrum; and the spectrum has effected a change in the sensitive salt of silver, as is shown by the blackening on the application of what is called a developer. The cause of the change in the sensitive material is what I first address myself to.

To conceive a right notion of photographic action we must first of all conceive, in the most elementary manner, the structure of matter. The structure is beyond our actual visual acquaintance, but we may be able to visualise it from the way it behaves; we have to draw our conclusion about it from evidence of an experimental nature. What we want to get is a mental picture of matter.

Physicists have come to the conclusion that homogeneous matter is composed of molecules, or small masses which are altogether similar one to another, *i.e.*, they have the same composition. In different matter these molecules, have different weights. Further, it is believed that the molecules, or the small particles of matter, are themselves composed of atoms, which we take to be the fundamental unit of matter. Now, from experimental data, Sir William Thomson and others have come to conclusions as to the limits of the size of these molecules, and also as to their distribution in space. From the kinetic theory of gases, it is concluded that the diameter of a molecule lies somewhere between one twenty-five millionth part of an inch and one two hundred and fifty millionth part of an inch. Further, in gases it is conceived that the molecules are free to move in straight lines in any direction, the direction being altered only when the molecules collide; that is to say, when they strike one against another. In a liquid, the particles are bonded much more closely together, and the free path of the molecules is very much shorter. That is to say, that they cannot go

from one place to another without very much more frequently coming into contact with other molecules ; and the molecules pass from place to place at a very much slower rate than they do in gases. A solid, such as is our silver salt, is conceived to be such that the molecule has no free path, but is confined in a limited space in which it can oscillate, moving round a mean centre. As to the distribution of these molecules in liquids and solids, Sir William Thomson has arrived at very definite conclusions also. In a lecture at the Royal Institution, he said that he concludes that in every ordinary liquid, or transparent solid, or seemingly opaque solid, the mean distances between contiguous particles is less than one twelve millionth of an inch, and more than one two thousand five hundred millionth part of an inch. Those are big figures, but still the distance apart is very small. "To form a conception of this," he says, "imagine a globe of water as large as an ordinary football to be magnified to the size of the earth, each constituent molecule being similarly magnified. The magnified structure would be more coarse grained than a heap of small shot, but probably less coarse grained than a heap of footballs." So you see that, by magnifying to this extent, you have a coarse-grainedness which, of course, is only relatively coarse grained after such an enormous magnification. Or you may put it in a different sense. If you magnify eight thousand diameters by an ordinary microscope—and that is about the limit to which a microscope will magnify ; and if you magnify that eight thousand diameters again eight thousand times, you would be able to see the molecular structure of water. So much, then, for molecules.

We will now turn to the atoms. These will not bear such a very large disproportion of size to the molecules as do the molecules to the smallest visible particles. We must, however, I think, conceive that every atom (and this is an important point) is charged with energy very much in the same way that the magnet is charged ; only, instead of two poles, as a magnet has, each atom has only one pole. It is unipolar.

Now, suppose that this energy is something like electrical energy. We know that positive repels positive, and that negative repels negative. And further, we know that the positive energy will attract what is called negative energy ; and if the two be exactly equal when they combine, of course there will be a neutral state. But in the case of the atoms of matter, circumstantial evidence tells us that the amount of electrical energy which is upon a given atom of matter—if you like to put it in that way—is never the same as it is upon another atom of matter ; that is to say, there is always a surplus of one over the other. Thus we may have an atom charged with what we may call *plus* 2 of energy, and another one charged with *minus* 1 of energy. Those two atoms, on coming together, give you a result of energy of plus 1, and this would again be capable of attracting another atom of matter which was charged with a negative energy, and so on. From chemical considerations, it would appear that plus and minus energies of different atoms, as I have said before, are never exact multiples of one another, and that when they are bonded together there is always an excess one over the other. A good example of the energy of the combination of atoms together may be shown by the combination between a gas, chlorine, which we have here, and the metal antimony, and you will see that when the latter, as powder, is thrown into the former, the two combine with an evolution of heat, showing that a vast amount of energy is given out. The chlorine and the antimony form chloride of antimony ; that is to say, five atoms of chlorine and one of antimony. [A small quantity of finely powdered antimony was dropped into a jar of chlorine.] You see the evolution of heat between those two ; so much, in fact, that the chloride of antimony, as it was formed, was at a perfectly bright white heat. The case immediately before us is the silver salt. Let us experiment with that in a similar way. Into the chlorine I will throw some powdered silver, and I wish you to notice the difference between the results in the two cases. [A small quantity of the powdered silver was dropped into a jar of chlorine.] You see that the combination between the silver and the chlorine only produces a red heat, whereas antimony produced a white heat. In other words, the combination between antimony and chlorine is much more vigorous than the combination between silver and chlorine. If you had to separate the atoms of chlorine from those of the antimony, you would have to use very much greater force than if you had to separate the atoms of silver from the atoms of chlorine.

When two electrified bodies attract one another, they attract one another inversely as to the square of the distance. That is to say, if there is a distance of one foot between them, they attract one another with a force of say—

1. If they are two feet from one another, they only attract one another with a quarter that amount. Supposing atoms attracted one another according to the same law, then of course they being so very close to one another, the attraction would be considerably greater than if they were visibly apart.

But besides this attraction between atoms comprised in the molecules, there also seems to be a repulsive action, into which I will not enter more fully now, because that would be almost beside my subject ; but I may say that besides the atoms attracting one another (we will take chloride of silver for instance) when they get within a certain distance of one another, they repel one another, and so there is a continual oscillation between the atoms composing those molecules.

I will try to show you on the screen how we can picture the motion to ourselves. It is only a mental picture, but still it will give us a sort of idea of what happens. [An image was thrown on the screen by means of reflection].

In this circular glass trough of water is floating a little magnet, the magnet being held at the surface of the water by a cork. Passing round this coil, which is large enough to surround the trough, is an electric current from three Grove cells, and if I place it round the cell which contains the little magnet, and not quite on a level with the water, you will find that the single magnet goes into the centre of the water. It is repelled from the sides by the current that is floating round that wire. Well, now, we have here one magnet. Suppose I put another magnet in. The ends attached to the cork have poles of the same name. They repel one another to a certain extent, and yet the force from outside makes them go as near one another as possible. By moving this coil vertically we can make them separate and oscillate, and we can picture to ourselves the way in which two atoms in a molecule may oscillate, and be attracted, and yet repelled one from another. I put another little magnet in, so now there are three; and here perhaps we have a picture of chloride of silver, which I say is composed of one atom of silver and two atoms of chlorine. We can still make them vibrate and oscillate. Here we have a mental picture —at least it is a mental picture to me—of the way in which the atoms of chloride of silver may be made to oscillate. Again I take four, and we repeat the same thing. Here we have a picture of ammonia—three atoms of hydro-gen and one of nitrogen oscillating. And so

I might go on. I might put five or six or a dozen in, and we might get some idea of the way in which they would all oscillate.

Here, then, we have endeavoured to draw from visible phenomena a mental picture of the way in which atoms of a molecule are vibrating.

I must, however, call to your mind that those magnets are vibrating only in one plane, whereas of course the atoms of a molecule are vibrating, not in one plane, but in space of three dimensions ; but anyhow, I hope that you have got into your mind at all events the same kind of mental picture regarding the oscillations or vibrations of the atoms which I have in mine. I think that the case of the magnets is a particularly happy one, because from all the evidence which we have at present we are led to the conclusion that all atoms of matter are really charged with electricity, or what answers to electricity of either one name or the other; that is, either positive or negative.

Now, we will throw a spectrum on the screen. I will call to your recollection what it is. I am now going to send the light of the lamp through this bisulphide of carbon prism, and I need scarcely say that the prism has to play an important part in spectrum photography. The wave length of the red is about one forty-thousandth of an inch, and the wave length of the violet, which is on the left of the screen, is about one fifty-seven-thousandth of an inch. Each ray of light is transmitted in air at the rate of about 190,000 miles in a second. Thus the number of vibrations of the red rays is 500 million millions, and 700 million millions in the case of the violet rays, and this rapid succession of blows batters against anything upon which they fall. The mean violet, I may say, is the photographic light *par excellence*, and we shall recollect that such rays might beat upon the sensitive salt which we expose to it 700 million million times in a second. Therefore, you see, if you give an exposure of the 100th of a second you still have seven million millions of vibra-tions beating on the sensitive plate, so there is ample vibration to effect any change on the molecule of silver chloride, supposing always the amplitude (or distance of swing) is sufficient. Instantaneous photography will not be complete, I suppose, until you can reduce by a million times.

We may take it that an atom vibrates some-what in the same way that a pendulum vibrates. Here I have a very rough contriv-

ance to show what I mean. I set the pendulum swinging. Now picture to yourself that the bob is an atom, and picture to yourself, also, a wave of light falling upon that pendulum; if the wave of light be synchronous with the pendulum, it will increase the swing, or, in other words, it will increase the amplitude of the swing of the pendulum. For a rude illustration, suppose I take puffs of my breath as illustrating the beating of the wave of light, and suppose the atom to be at rest; I begin, and I blow; every time I give a well-timed puff to that pendulum, the pendulum increases in amplitude, or swing. But if my breath does not come in unison with that pendulum [blowing irregularly], you see that very soon I should bring that pendulum to rest; in other words, unless the wave of light beats in unison with the atom, the amplitude cannot be much increased. It is true that as long as the breath strikes the bob as it is going away from me the amplitude is increased, but if the puffs are regular and slightly more rapid or slower than the pendulum oscillation, the amplitude must eventually be diminished.

Here we are met with a difficulty, and a very great difficulty. I exposed the plate to the spectrum, and you see the blackening not only was where one wave of light synchronised with that atomic motion, but that there were a great many waves of light, extending from the ultra-violet as far as the blue which affected it. How are we to get over that? That is a difficulty which has puzzled a great many people. I would ask you again to form a mental picture of how that could possibly arise. I do not say that it is the correct way, but all I say is that you can form a picture in your own mind, can conceive of how it could be done. Here, I have another pendulum, but in this case the bob is attached to an elastic band. The time of the vibration of a pendulum depends upon the length of the pendulum. Therefore, if during the time of the oscillation of the pendulum I alter the length, I also alter the rate at which the pendulum vibrates during any instant. I pull down the weight of the pendulum, and at the same time set it swinging, and you will see that during every part of this motion the length of the pendulum is altered so that a great many differently timed puffs of breath might be synchronous with the pendulum. It is not like this other rigid one, where it is of a definite length, but here the length of the pendulum keeps altering. I only ask you to form a mental picture of the way in which such

a thing might happen. In this way you can picture to yourself how a molecule might vibrate, and still be synchronous with more than one vibration of light.

Proceeding another step, I may say at once that, to my mind, the theory of the photographic image is well established. I know that there are some people who differ, but in my own mind the formation of the photographic image is not a working hypothesis, but it is a theory. The difference between a working hypothesis and a theory is this—that you adopt a certain idea and say, "I will work upon that idea, and see whether every experiment fits with the idea I have conceived. If it does not fit, then that working hypothesis is no use. I must give it up, I must take some other working hypothesis." As regards the idea of the formation of the photographic image, I think that it has passed from the stage of the working hypothesis into one of a really acceptable theory. It does not follow that everybody will accept it, but still it is an acceptable theory, accepted by most people. I am not going to enter into that very strongly to-night. At the next meeting of the Photographic Society, I propose to deal with it more fully; but, at the same time, I just wish to state publicly, to perhaps a more extended audience than I shall see at the Photographic Society in about three weeks' time, that this photographic image theory—that is to say, the theory as to the action of light upon molecules of silver—is as well established as, at all events, the wave theory of light itself. Now, I am going to show you an experiment which, perhaps, will help to illustrate what I mean by the vibrations of atoms. In this slide I have got a gelatine plate, and I have a little flat iron which has been made warm. It is rather too warm to be borne comfortably. Here I have a phosphorescent plate, which I propose to illuminate with magnesium wire, in order to give an even source of light; I press this flat iron against the back of the plate which is in this slide for a short time. I shall not let the plate cool, but while it is warm I will expose it to the phosphorescent light for about fifteen seconds. The plate is now allowed to become cold, and is developed. If everything has gone right, we ought to have something which shows us that the oscillations of the atoms of bromide of silver (which is the silver salt on this plate) have been given extra amplitude by the action of the heated iron to the back of the plate. I am afraid that I cannot show you the development in the light. [When the develop-

ment had been carried out the plate was shown.]

You now see we have a picture of this flat iron produced by the deeper blackening of the heated part, though the whole plate was given but a short exposure to the light from the phosphorescent plate. I will impress this further upon you. I have here a collodio-bromide emulsion plate. But in this case, instead of heating it by a flat iron, we will heat it by immersion in hot water. Of course a collodion plate is not so sensitive as a gelatine plate. I put it into cold water for a short time to moisten it, and then dip half of it into some nearly boiling water; on withdrawing it, I expose it to this candle, and develop it when it gets cool, which we effect by placing it a short time in cold water. It will be seen that the part immersed in hot water is much blacker than that which was exposed cool. If I heat the plate and allow it to cool and then expose, there will be no effect. The plate will develop normally, for the increased amplitude of vibration will have ceased, and the light will have to perform the same work on each part of the plate. Now, in whatever manner increased amplitude is given, when the cause of the increased amplitude is withdrawn, the amplitude will cease in the same manner. The case before us next was the cause, and it will cease after a very short period, in other words, when the plate gets cold. One of the chief reasons against what we may call the "vibration theory" of the photographic image, namely, that the molecule is unaltered by the action of light, is this—that the increased amplitude would cease with the same rapidity with which it would cease when the hot iron was applied to the back ; that is to say, after five or ten minutes the amplitude of the vibrations would come back to the normal extent, a condition which is not fulfilled in the photographic image.

I can illustrate this in a very visible manner. I think you can all see this phosphorescent plate. Now, what is the reason of that phosphorescence taking place? It is that the atoms of the molecules which comprise this phosphorescent material are swinging in a certain rhythm, which gives us the sensation of light. Now, if I apply a hot iron to the back of this plate, I think at once you will see that the image of the hot iron is present. Here is the same kind of action taking place in the one case as in the other.

Now we come to another point, which is a slightly different one, and that is the energy of radiation. I may say that the energy of radiation is a subject on which I could discourse for a good many hours, but here I can devote but two minutes to it. I must try to make it as clear as I can. I hold in my hand a little instrument which is called a thermopile, which you see has a narrow slit which could be narrowed to any degree of fineness ; attached to it is a screw motion, which will make that slit travel along the base of the instrument ; beneath that slit are some thermo-electric couples. It is not my business to enter into how they are made, but still we know that, when thermo-electric couples are heated, an electric current is generated sufficiently strong to cause the needle of a galvanometer to deviate ; and the amount of energy of radiation which falls upon the face of the pile can be measured by the deviation of the galvanometer needle, from the energy heating the lampblack at the junction of the couples. In a great many experiments which were made, this thermopile was caused to travel along the spectrum by the screw motion, and at every part of the spectrum at distances of, say, a quarter of a turn or half a turn of the screw, the amount of deviation which was given to the galvanometer needle was read off. By that means we are able to compare the energy existent at different parts of the spectrum. The spectrum used was that of the electric light, the comparative energies at different parts of its spectrum I have in the diagram—at five turns of the screw we have the end of the red, and at different turns we have the yellow, the green, the blue, and the violet ; whilst from five to twenty we have the dark rays which lie below the red, and with which we are not to deal to-night at all events. The energy, I may say, being measured by taking the amount of the deflection of the galvanometer needle, you will see that the dotted line divides the energy area into two parts.

On measuring this area of the curve in which lie all dark rays, and the area of the curve for the visible rays, it will be found that, roughly speaking, the energy of the latter rays are about half that of the former. But for photographic action we do not have anything like that amount. The red rays for ordinary photographic work are useless ; and why that is we shall see by and by. We will say that the photographic action stops at the blue, and we find that the total energy of radiation which is used for photographic purposes in

the electric light, is only about one-hundredth part of the whole energy of radiation. The remaining ninety-nine parts are wasted as far as photography is concerned, except in so far as they heat up the molecules in the same way as the flat iron heated up the molecules on the photographic plates. The other curves show the energy of incandescent lamps. You will see that they have very little of what is called actinic power; that is to say, they have very little blue ray at all compared with the arc light. In the lowest curve we have a lamp at only a yellow heat, the middle curve being that at a white heat, and you will notice the enormous difference there is in the energy between the two. The energy of the middle curve, which measures the total energy of radiation from the incandescent light, is about twelve times that of the visible power. Yet, when you have to measure the photographic part of the spectrum, you will see that it is only about eighty. That is to say, supposing you have a filament of an incandescent lamp which is one-hundredth of an inch wide and half-an-inch long, then if you take an arc electric light and cut off from the glowing positive pole the same area, the photographic value of the one, area for area, is about eighty times that of the other. [A spectrum was thrown on the screen.]

I will ask my assistant to put in front of the slit something which I showed you at my last Cantor Lectures, and which I dare say you have forgotten all about. That something is a film of the same silver salt with which I photographed the spectrum at the commencement of the lecture. You see that it cuts off all the violet, and well down into the blue. I want to show you that the colour of the photographic spectrum is perfectly different from that which the human eye can see. I wish to show you a little device by which, perhaps, I shall be able to give you an idea of the integrated colour. A tolerably bright spectrum is on the screen of the camera; I raise the screen so that the spectrum falls on a lens placed a little beyond it; and if we had time, I dare say that we should be able to get a screen placed in the focus of the second lens, so that the recombined colours would form a white patch, without the slightest tinge of colour. We have got a white circle, however, which is sufficient for our purpose, though at one margin there is a very narrow red fringe to it. [A white patch about 6 inches in diameter was formed on a transparent screen about 6 feet away from the camera.] In the place where the coloured spectrum is in focus, I place a horizontal aperture, about ¼-inch wide, and by a little arrangement I can, by strips of card, cut off any colour I like from falling on the collecting lens, so that it recombines only the remaining colours.

You remember that the photographic spectrum does not extend as far as the green, ordinarily speaking, so now I cut off all rays as far as where the photographic spectrum begins, and you can see the colour of the light, which is really useful for photography. It is a sort of sea-green colour. If I were to take that light, and pass it through a slit and a prism, you would soon find that the whole of that spectrum would be photographically active, because all the light which is not photographically active has been cut off. I shall have to revert to this in my next lecture.

I will show you one more method of recombining the photographically effective colour disc; that is by taking the ordinary disc, and cutting out the red and orange. We have, then, only the green, the blue, and the violet; and those, when they are combined together, ought to give you pretty nearly the integration of the colours which are ordinarily photographically active. I will ask my assistant to spin it in front of the lantern. [The instrument was rotated.] I do not know whether you can all see the colour-chart which I hold in my hand, but those who can will see that the colours, when placed in the blue-green light, appear totally different from what they did in the whiter light. The yellows are much deepened, and the reds are much blacker.

I will ask now to have the spectrum thrown upon the screen once more, and we will again pass this colour-chart through the spectrum. The colours are very pure for pigments. I think that it is the finest colour chart of the spectrum which I have ever seen. It is one prepared by Professor Piazzi Smyth, and appears in his Madeira spectroscopic observations. Notice that the blue appears perfectly black when the chart is in the red, the red at the left hand being brilliant. Passing it into the yellow, the yellow is vigorous; the blue is black, and the red undimmed. Upon my passing it still farther on in the green, you will see that the red is blacker, and the orange is blacker, whilst the yellow still keeps its colour, and the blue begins begins to get more bright. Passing it still farther on into the violet, we see that the yellow is now perfectly black, the red has gone, and the blue begins to shine out.

Passing still further, you will see that the blue still shines out, but is less intense, all the other rays appearing black. Upon my passing it again rapidly through, you will now be prepared for the changes that take place. In this lantern, which has been used to form the spectrum, the light passes through a slit. The slit, you see, is perfectly straight, with parallel edges. Now comes the question, "Is it necessary that light, in order to be decomposed into a spectrum, should be passed through a slit of this description, or what shapes may it be allowed to take?"

I propose to try to answer this query in an experimental manner a little. First of all, we will see what the effect will be if we use no slit at all. You see that the colours are not pure. I replace the slit, and you will see at once that we now have, not the various colours light overlapping, but a tolerably pure spectrum. Now let us take a slit of another shape—a zig-zag slit; and here we have another form of spectrum delineation of the rays. Placing a metal in the arc, the bright lines due to the vapour flash, and, it will be seen, take the zig-zag form of the slit. There is, then, no particular reason for using a straight slit, except convenience. Then, again, I may take a ring slit, and to test its value we will put a little silver in the arc to show you. I am not simply showing this as a pretty experiment, but I want to show you that such a slit is absolutely useful in photography, the spectrum of silver now on the screen shows rings of different coloured rays. It is a very pretty spectrum. This form of slit is extremely useful in one branch of spectrum analysis.

You are perfectly aware that, during a total eclipse, the body of the moon covers the sun; but that there are seen beyond the dark moon certain red protuberances which belong to the sun, and are known as "prominences." It has been the work of astronomers to determine the composition of those protuberances, and also to form a definite idea of the corona of light which surrounds the body of the sun, and can only be properly seen during a total eclipse. The picture on the screen is a representation of the total eclipse of the sun which took place in Egypt in 1882. It is a negative picture, and of course the dark halo which you see around was seen as a bright halo, and the white disc is the black moon. On the left-hand bottom corner you may notice the comet which was discovered during the eclipse, and which received the name of Tewfik, after the Khedive of Egypt. Round the disc of the moon are little prominences. Those prominences are vastly more bright than the corona itself, which is the halo extending some distance round the sun. Thus we have a bright ring of light round the moon surrounded by a feeble light. The former, when viewed by means of a lens in front of which a prism is placed, shows rings of colour composing these prominences, and of course these rings can be photographed.

I now show a transparency of a photograph taken in Egypt by means of the slitless camera, from which much valuable information has been derived.

The ring slit was used by an Italian astronomer about 1870; but the eclipse in Egypt was the first time it was entirely successful for photography.
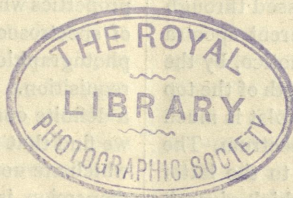
LECTURE II.—DELIVERED APRIL 27, 1885.

In my last lecture, I left off with the use of the slit in the spectroscope, and I showed you, I think, that under certain circumstances the slit which had the form of a ring was useful, having previously demonstrated that it was not necessary that the slit should be straight, but that it was most convenient that it should be so. I will next deal with the subject of the prism. We know that prisms are employed to separate the different coloured rays, as each colour is differently refracted as it passes through the prism, and it is this difference in the index of refraction between the red ray and the violet ray which gives the amount of dispersion in forming the visible spectrum. Of course, if we go beyond the violet, there are invisible rays, while again below the red there are also dark rays, which also have their indices of refraction, but I wish to show you the influence that the material of the prism itself has on the dispersion of the visible spectrum.

I have here a prism of 60° built up of six or seven different triangles of glass. It is apparently homogeneous, but when we pass light through it we shall find that it is anything but homogeneous; in other words, the different portions are differently refractive. The different portions of the prism are all glass, as I have said, but of different densities, and the denser the glass, the more are rays refracted, and the greater dispersion between the red and violet there is. [A slice of light was passed through this built-up prism, and the different spectra thrown on the screen.] You will notice, by the spectra on the screen, that the length of the top spectrum between the red and violet is much smaller than that of the bottom spectrum. The glass which gives the dispersion to the latter is much denser glass than that which gives it to the former. Practically speaking, therefore, we may say the denser the glass the greater refraction, and the greater dispersion there is. For most purposes in spectroscopy, it is as well to use as dense a glass as possible in order to get the maximum amount of dispersion. I will now combine three prisms together, two of a light glass, and one of a denser, and we get a combination, in which,

although the main beam will pass straight on to the screen, yet the presence of dispersion is also shown by the formation of a spectrum. This is an example of what is called a direct vision prism. The spectrum is given by the differences of the refractive indices for each ray in the two kinds of glass. For some purposes this kind of compound prism is very useful, and particularly for lecture experiments, but, as a rule, for photographic purposes I should not recommend it, on account of the internal reflections which take place between the different surfaces of the glass, though they are cemented together. You must recollect, wherever there is a difference in density between two media, in other words, a difference in the refractive indices, there is always a certain amount of reflection, and those reflections, being white light, are rather apt to fog the plate, and give you false notions of what you get in the photograph.

We come now to a much more important point with regard to the spectrum, and that is, what is the best material to use. In those prisms which I have already shown you, the material was glass. Now glass is, comparatively speaking, a mixture of materials, and has no definite chemical formula; but when we come to a material which has some definite chemical formula, we find that, as a rule, it has certain properties which are invaluable in certain forms of spectroscopy, more particularly when the photographic plate has to be brought into requisition. Quartz is an example of this; it is a definite compound of silicon and oxygen, and we find that it has certain definite advantages which are not to be found in glass prisms. The dispersion is not quite so great as it is with glass, but, on the other hand, it lets through rays which are cut off completely by glass, as I hope to show you on the screen. This quartz prism has very well-worked faces, and we will send a beam of light through it, and then proceed to investigate its behaviour. [Spectrum thrown on screen.]

I may further say, in reference to this, that the condenser in that lamp is quartz, the lens

is quartz, and the prism itself is quartz, so that we are dealing with nothing but quartz. Now, the question comes, is there any advantage to photographers in using such a material as quartz. Let us first see the extent of the spectrum. By placing a card which has been washed over with quinine in the ultra-violet part of the spectrum, you are able to see these ultra-violet rays glowing with a pale blue light, and you will notice to what a great length these rays reach beyond the ordinary visible point of the spectrum. Now, by placing a piece of glass in front of the slit, you will see that the ultra-violet spectrum is very much shortened; in other words, the glass has absorbed these rays. I may repeat the experiment with a card which has been brushed over with paraffin oil, and the same result holds good.

I have here a photograph of the electric arc taken in another manner, to which I shall have to direct your attention presently. The ight in this case has to pass through no glass whatever. The spectrum was taken by a diffraction apparatus; for the top part of the spectrum a glass was interposed in front of the slit, and we see the difference there is in the spectra, owing to the use of glass in one case, and not in the other. The glass apparently cuts off many useful rays; but I will now draw your attention to the solar spectrum taken in the same way, in which there has been a glass placed in front of the slit for one spectrum, and not in the other. Both spectra, practically, reach the same limits. We now can answer as to whether it would be advisable for photographers to use quartz lenses for ordinary photographic purposes or not. Recollect that every ray of light you saw fluoresce on the screen is useful for photographers when they are using a light such as we have in the electric light. You will see, then, from that, if the electric arc light was usually employed, all those rays which are cut off by the glass could not be utilised by them, and, therefore, there would be so much power wasted. Now photographers, as a rule, do not work with the electric light, but with sunlight; we have seen that in the solar spectrum taken under similar conditions, the glass practically cuts off none of the ultra-violet rays; the atmosphere of the earth, or of the sun, or both, cuts off the extreme ultra-violet rays before the light reaches us. We therefore come to the conclusion that, so far as photographic work with sunlight is concerned, there would be no advantage in using a quartz lens over the ordinary photographic lens. Some years ago, Mr. Claudet made an agate lens, which he considered would give him greater advantages over the ordinary photographic lens, simply because he could utilise the ultra-violet rays, but I think you will see from this there is no advantage in using such a lens. Remember, however, if you are photographing the spectrum of the electric light, or using it for illuminating a sitter, there is a very great advantage in using quartz. We may use another definite chemical compound in the shape of Iceland spar. I have here a very beautifully worked prism of Iceland spar, which has a definite composition of calcium and carbon, and I dare say that we shall reach very nearly to the same ray limit as we did in the quartz experiment. Iceland spar holds an intermediate position between quartz and glass. It was with such a prism as that that Dr. Huggins took his famous star spectra, and I thought it might interest you to throw one or two of these on the screen. They are very small, but the definition is very beautiful. Many of the black lines in these spectra indicate, probably, hydrogen. It remains to be seen whether Dr. Huggins has attained any advantage in using Iceland spar instead of glass, for if the ultra-violet stellar light is absorbed, as with sunlight, no advantage would be gained. I may mention that he gives the composition of the stars by reference to the spectral lines of well-known elements.

One more point is this: Would it be advantageous to use a mirror instead of a lens? There is a great deal to be said about this, particularly in spectroscopy, where we have to examine everything minutely. The material we utilise most easily in the case of a mirror is silver; that is to say, we get a glass mirror, and silver it on the front surface. Now, the question is, does the silver reflect every ray in the same way that quartz would transmit it? Here I have a photograph which should give an answer to that question. The bottom half of the spectrum was taken as reflected from a quartz surface, the top half of the spectrum was reflected from a silver surface, and you will see that at one certain part of the latter the rays are very nearly absent, though beyond that again they are present. Where those rays are wanting is just at the end of the solar spectrum, and therefore, when using sunlight, it is no great advantage to use a quartz reflector over a silver reflector. In spectroscopy it is necessary to know exactly the

qualities of all the substances with which you are dealing.

One question in photography and in spectroscopy is, what width of slit you would use—what slice of light would you allow to pass through? Here let me give you a demonstration. In the centre of this black disc there is a fine line of light, and there is a micrometer screw by which we can tell how many thousandths of an inch wide it is. As a rule, about $\frac{1}{800}$ of an inch is the dimension used for ordinary work.

I have been referring to the photographs to two spectra on the same plate, and I must show you how it is managed. For this purpose, it is necessary to have an adjunct to the slit, and that is a shutter, which is able to cut off half the slit at one time, and afterwards leave that part open and close the other half already used. By this means we can get one spectrum adjacent to another. In comparing spectra of different metals with each other, we are able to tell whether we have any two lines coincident one with the other.

Photographic spectroscopy is the easiest thing in the world when you know how to do it, but it requires a deal of patience to learn every dodge. As a rule, a photographer is a patient man; indeed, there ought to be no class of men who have more patience than photographers; hence spectroscopy should not be difficult to them.

Here is another piece of apparatus which is very useful in the spectroscope. It is an apparatus by which you can take a great many spectra on one plate. I need not enter into its details, it is simply a dark slide, which by a rack and pinion motion can be raised, so that the plate gives a fresh surface at each exposure. The only light accessible to the plate comes through an opening of about three-quarters of an inch wide cut longitudinally in the shade. By this method we can get about sixteen different spectra of different materials on the same plate.

Here is another piece of apparatus which is also useful in investigations with photography. It is, a slide in which you can expose plates in different gases or liquids, that is to say in water, in alcohol, in nitrogen, and so on. It is essentially a glass cell which slips into a dark slide especially adapted for it; on the top there is an air-tight junction which is screwed down, and there are two little tubes through which you can fill the cell with gas or water, or whatever other material you wish to use. This is very useful in investigating the behaviour of different sensitive salts under different conditions of moisture, pressure, &c. This cell has been used in a great many hundred experiments, and I hope it will be used in a great many more. Those who are going in for spectroscopy should not be without such an apparatus as this, for I do not believe much real investigation can be done without something of the kind. The sensitive salt of silver acts differently when isolated from its atmospheric surroundings, and the only way to ascertain how it does so is to expose it with other surroundings, and to differentiate the results one from another. There is no such thing as a perfect vacuum; you cannot say you expose a plate in vacuo, and, for this reason, I say you have to differentiate between the different media in which you expose a plate, in order to get at the true result which would happen supposing you could expose the plate in vacuo.

You saw last time how you could recombine a spectrum by means of a lens, to form white light.

Now, I want to show you that it is not impossible to develop a plate in white light. I expose a plate behind a negative to the electric light, and in the cell which is placed in the patch of white light is some developing solution (which is quite colourless). The plate is dipped into it. The image comes out into it, although exposed to white light, without fog, which was supposed to be an impossibility. I have another plate placed behind the same negative. I expose half of that plate for half a minute to the white light on the screen, and the other half to apparent darkness, but in the same position on the screen, for a couple of minutes. The plate on development shows that the half which was exposed to what was presumably white light gives no image, while the half exposed in the dark shows a perfect picture. I dare say many of you have guessed my trick, for it is merely a trick, but for those who have not, I will show you how it is done. It is perfectly easy, by mixing two elements of light of different refrangibility, to produce a colour which, at all events, to our eyes is a white light. But you must not take it for granted that wherever you can see white light you can photograph with it, because it is quite possible you may not. It is only a trick, but some of these tricks bear fruit in a very practical manner. I will re-form white light again, and we will examine it by means of the colour-chart I showed you

last time. You will see that when the red is placed in the white light there is blackness—no colour whatever—the yellow looks bright, as does the blue, all the other colours are gone except some few which are of a non-descript colour. The meaning of it is this, we have simply a combination of yellow and blue, which gives us the appearance of white light. [The blue and yellow rays were shown to be coming through two slits placed at the focusing screen of the camera.] The blue has no power of acting on the iodide or chloride of silver, neither has the yellow, and, therefore, the white light which is made by the combination of those two colours is powerless to act on films made of such materials as those. We can also produce a white light, practically, by a red and green, and if we examine this (which is a very good imitation of white light) in the same way, you will not see the whole series of colours in the colour chart any better than you did before. The red comes out perfectly, but the blue is no longer visible; the blue becomes green, and the violet becomes red; the yellow is also not intense. This is because we have only two colours present, viz., the red and the green. The apparent darkness to which we exposed the one-half of the plate was in reality the dark ultra-violet light, and I need say no more regarding that.

I told you last time that this was a very interesting way of studying the spectrum. You see how, by combining two lights together, you may have a light which is perfectly safe for certain salts of silver. On the screen is the spectrum taken on the three ordinary salts of silver—chloride, iodide, and bromide. The iodide stops exactly at the violet. Below that light we have no action whatever, and we, therefore, may expose an iodide plate with impunity to any rays below the violet. A bromide plate, you see, is sensitive down as far as the yellow, and, therefore, it would be impossible to develop a bromide plate in such a light as I showed you just now, whereas iodide is perfectly capable of being developed in such white light; the chloride again stopped very nearly with the limits of violet, so that it would be safe to develop a chloride plate in such a light.

[The lecturer concluded with a brief explanation of the diffraction spectrum.]